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ABSTRACT

Task analyses have traditionally been framed in terms of overt behaviors performed in accomplishing tasks and goals. Pioneering work at the Learning Research and Development Center looked at what contribution a cognitive analysis might make to current task analysis procedures, since traditional task analysis methods neither elicit nor capture cognitive components of the job. This paper describes an approach to cognitive task analysis, and reports on initial case studies trying out the methods used. Specifically, the approach attempts to capture two aspects of a job that have been generally overlooked by traditional task analysis: (1) describe job performance not only in terms of overt behaviors, but also in terms of the underlying knowledge content and thinking processes, and (2) capture not only the formal but also the informal aspects of the job. Knowledge about jobs is analyzed into four knowledge representation types: factual knowledge, imagistic knowledge, procedural knowledge and mechanism (or mental model-type) knowledge collectively referred to as FIPM. This FIPM model of cognitive task analysis is found to be effective in capturing rich knowledge content both in relation to the performance of specific tasks, and in relation to the general work setting. (Contains 13 references.) (Author/AEF)

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ED 383 287

Title:

Using a Knowledge Representations Approach to Cognitive Task Analysis.

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Task analyses have traditionally been framed in terms of overt behaviors performed in accomplishing tasks and goals. Recent research has described the central role of cognitive factors involved in performing jobs ranging from dairy truck loading (Scribner, 1984) to paper pulp manufacturing (Zuboff, 1988), ship navigation (Hutchins, 1990) and software debugging (Riedl, et al., 1991; Flor and Hutchins, 1991). Pioneering work at the Learning Research and Development Center looked at what contribution a cognitive analysis might make to current task analysis procedures (Glaser et al, 1986), since traditional task analysis methods neither elicit nor capture cognitive components of the job. In the current paper, we describe our approach to cognitive task analysis, and report some initial case studies trying out our methods.

Specifically, our approach has sought to capture two aspects of a job that have been generally overlooked by traditional task analysis: (a) describe job performance not only in terms of overt behaviors, but also in terms of the underlying knowledge content and thinking processes, (b) capture not only the formal but also the informal aspects of the job.

Drawing upon basic research in Cognitive Science we analyze knowledge about jobs into four knowledge representation types, namely factual knowledge, imagistic knowledge, procedural knowledge and mechanism (or mental model-type) knowledge (Black, 1992).

Factual knowledge gets at "knowing *that* something is the case". It is best represented as a propositional network (Anderson 1983). The basic unit for this kind of knowledge is the proposition, which is composed by a relation and the concepts or objects (idea units) that it interelates. Together the relations and idea units form a web of meaningfully interconnected ideas. Sets of highly interconnected ideas form schemas, that are integratve higher level units. Schema complexity is a measure of the sophistication of factual knowledge used in the performace of a task.

Imagistic Knowledge, refers to "knowing *what something looks like*". Although a mental image has pictorial elements it needs not to be an exact picture of the thing represented. Instead, the mental image is an arrangement of just the pictorial elements that constitute meaninglul imagistic properties of what is being represented and the spatial relationships between them. A useful represenetation of imagistic knowledge is the Pixel Coordinate Network, proposed by Kosslyn (1980). Through use of this representation the overall image can be mentally transformed, for example it can be segmented into subimages of meaningful pictorial elements with their specific spatial coordinate (a 'zoom in' kind of operation). These pictorial elements can be used for imagistic reasoning by means of such mental transformations. In our model, imagistic complexity is a function of the number of pictorial elements and density of the relationships between them. This serves as an indication of the sophistication of imagistic knowledge being used.

Procedural knowledge addresses "knowing *how* to do something". It can be represented as a system of production rules in the form of condition-action pairs. Simple production rules are clustered in plans which integrate highly interconnected actions. Having procedural knowledge accounts for more effortless free-flowing performance, in the execusion of a task. The level of sophistication of procedural knowledge is then indicated by plan complexity which is a function of: (a) the number of actions that are clustered in a plan and (b) the number of discriminating conditions to which the plan is sensitive (the number of alternative procedures for the same goal). In addition, the distribution of tasks among workers, by means of shared procedures, provides insightful descriptions of the underlying work organization.

Mechanism Knowledge is represented as a mental model. It involves knowing *"why* something works". (Stevens, 1983) It therefore refers to an understanding of the underlying structure of a system that allows for the procedures used to perform a task to have the desired outcome. While procedural knowledge allows smooth performance, a "mental model" provides easier derivation of new procedures and more complete diagnosis of problems that might arise. This knowledge is therefore important for tasks that vary a great amount and often involve dealing with novel situations. Mental model complexity (a function of the number of system components, the number of possible states of the mechanism and the number of transitions between these states) as well as mental model flexibility (the ability to represent the system in alternative ways relevant to particular problems) are used as indicators of the sophistication of the mechanism knowledge involved in the performance of a task.

We will refer to the four representations as FIPM in the rest of this paper.

Methodology

Our data collection is based on a combination of methods which stem from efforts in anthropology and cognitive science. The methods which were primarily used are as follows:

On-Site Observation

For on-site observation we draw upon the ethnographic methodological tradition. Ethnographic field methods are particularly suitable for documenting knowledge as situated (Brown et al., 1989) in a rich social context. We used observation to capture various aspects of the work context - physical space, work objects, social scene, actors and actions, time sequencing etc. In addition we entered the field with questions based on FIPM regarding observable clues as to the types of knowledge that the worker utilizes. For example, smooth execution of a task was indicative of possible existence of procedural knowledge. Our fieldnotes also include verbal reports by the workers about their various tasks.

Intensive Interviewing

A variety of interviewing techniques were used including storytelling, directed questioning and critical incident probes. In sequencing the interview techniques, it was important that the storytelling precede all other kinds of interviewing, which is in contrast to traditional task analysis protocols. We have adopted such a system for a number of reasons: (a) when open ended probes follow formal accounts of the job, elicited by means such as directed questioning, previous answers constrain storytelling (b) by capturing knowledge in context (in storytelling data) we are able to look at the FIPM knowledge representations as situated in rich contextual information including time sequencing, social interactions and affect. Having established this general context of knowledge we can direct our inquiry towards specific knowledge representations, without the danger that our data will be overly fragmented and (c) it provides "anchoring" which yields a more natural account of the type of information that we are looking for than does answering abstract questions. The subsequent question-answer processes are then facilitated by the fact that the worker and the researcher have established a concrete common ground of understanding.

Task Related Queries

The line of directed questioning is guided by the FIPM model as the questions probe for worker's use of particular knowledge representations. A primary tool used during this section of the protocol was that of the task matrix, a form which organizes workers' tasks in terms of the types of knowledge needed to perform those tasks. Information about this knowledge was elicited through verbal probes designed to capture the facts, images, procedures and mental models required in the performance of each specific task.

Critical Incident Probes

Critical incident probes are also FIPM based and are designed (a) to elicit alternative procedures to a goal and (b) to evoke mental models that may deal with atypical situations. In this case the FIPM notation served as a guide to elicit knowledge that is critical for efficient performance, even if it is not spontaneously evoked by the worker during the short period of data collection.

We addressed issues of reliability and validity, thus, through these efforts to triangulate research approaches. Through the examination of sites with such a varied assortment of tools, we were able to confirm our findings by looking for consistencies across data types.

After obtaining field notes and interview data from each site, researchers coded the notes into the categories of facts, images, procedures and mental models. In addition, the category "other" was used to hold data which did not fit into any of the above categories. This data in the "other" category was later partitioned into new areas such as goals, affect, social interactions, and technology integration. In cases where a given piece of information pertained to multiple knowledge representations, it was coded to include all of them. Each piece of data was then "tagged" with the worker's name, the observer's/interviewers name, the specific task to which the data related, and the portion of the protocol from which the data stemmed.

This method of coding allowed researchers to look at the data both by way of knowledge needed for specific tasks and by knowledge as it is organized independent of tasks. The structure of our data thus allows for flexible approaches to indexing patterns that exist across tasks, across jobs, and across workers. Each researcher examined for trends in the data, asking questions about: what types of knowledge are needed to perform each specific task, which types of knowledge representations are present in numerous tasks

distributed throughout the workers' responsibilities, which tasks constitute larger patterns in the organization of a given job, and how do different workers characterize their jobs in terms of different knowledge representations.

Thus our FIPM model is guiding, but not constraining, our data collection. Targeted questions and task matrix related queries were used to ensure that the main tasks of the job are recorded and that their specifics are coded in terms of categories recognizable to researchers, as well as in terms of FIPM.

Preliminary Findings

The protocol has been performed at 14 sites in the New York, Los Angeles and Palo Alto areas, by ourselves and our colleagues at the Rand Corporation. For the purposes of this paper we will consider six of the sites at which the cognitive task analysis protocol was enacted and the resulting data was analyzed.

site 1 - x-ray technicians in a hospital
site 2 - records center clerks in a law firm
site 3 - customer service department in a paper company
site 4 - order entry department in a clothing manufacturer
site 5 - aides in a home health agency
site 6 - copying center in a law firm

It is useful to frame the evaluation of our work to this point with respect to three questions that address our framework and methodology: (a) Is the FIPM framework generic enough to base a domain independent methodology on? (b) are the distinctions that the proposed formalisms make meaningful with respect to the knowledge that workers have about their jobs? and (c) are the aspects of job related knowledge that our methodology captures significantly more informative than traditional task analysis?

We have found the FIPM model of knowledge representations to be broad enough for the development of a domain independent method of cognitive task analysis. Our methodology was successful in eliciting rich and meaningful data across cases in which the nature of the job and the organizational structure within which the job was performed varied considerably. Each of the four representations could accommodate a variety of knowledge content (knowledge about tasks, knowledge about the social context, etc.). For example, depending on the specific nature of each job, mental model knowledge probes were successful in eliciting mechanism knowledge, organizational system knowledge and also models of social interaction.

The formalisms proposed by the FIPM model allowed us to capture differences between jobs in terms of cognitive demands. Depending on the nature of the job, different types of knowledge appeared predominant.

In the hospital setting in which x-ray technicians were looked at (**site 1**), for example, we were able to elicit detailed imagistic knowledge regarding body marks and angulation which is used to correctly position the patient and the equipment. Imagistic knowledge was also critical to the task of successfully evaluating the diagnostic quality of x-ray films. Together with being able to characterize the x-ray technician job as heavily drawing upon imagery, which in itself may seem like a trivial finding, we were able to elicit visual reasoning, and to document how images are tied to the procedures used to execute the tasks. The following examples from the data illustrate this point:

[GU, task list,]:"They say that we have x-ray vision because we work in x-ray. Whenever I have a case on the body or the trunk, we don't know where your stomach is, I don't know where your liver is, where the vertebrae are, I have an idea, but we use body landmarks. Depending on your body landmarks, because your elbow, on everybody, you let your arm drop to the side of your body, your stomach is at the level of your elbow, your gall bladder is at the level of your elbow, your gall bladder is at the level of your kidneys which is about L1. If you just close your eyes and you just picture it, if I just bring it down I'll get this part of the body that I need. I do that, it gives me a better picture."

[GU, Task-list, pp.20-21, supervising students, # M,I,P] E: What would be a kind of problem a student would come up with?
G: A student? A kid, they take a hand x-ray, right? You do it like this, then like this. A kid's hand's in a cast and they want to straighten the figures out, but they can't because it's in a cast. So it's like how do I

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do it? Put his hand down and shoot it. His elbow is locked, he's supposed to do an AP elbow like this, right, what you're supposed to do is you're supposed to put it like this, shoot it like that, and you're supposed to put it down, shoot like that. What I do is I put it on the V and I shoot straight. They're confused, it gives you the same film, just a different way.

With respect to the last example, it is important to note that although the overt procedures used by the technicians are standard each time, for any given x-ray there is specialized knowledge which informs and alters the technicians' procedures. The alternative procedures which experts have at their disposal involve considerably more than procedural knowledge. Cognitive task analysis has allowed us to elicit information about the facts, images and mental models which inform these procedures. Our ability to gather this kind of data speaks to the strengths of the FIPM framework, especially in comparison to other methods of task analysis.

The records clerk job (**site 2**) in a law firm record center provides another example which relates to this point. The record center job is highly procedural and all of its main tasks can be broken down into a series of steps: indexing, filing, binding, searching etc. Varying facts are continuously plugged in the procedures and specify alternative routes for execution. For example, the document's age indicates whether it should be searched in the on-line system or in the warehouse indexes and the type of law determines how documents will be bound. Given these characteristics this job, together with sites 3, 4 and 5, can be said to belong to a broader category of jobs related primarily to information processing.

The sophistication and volume of the record keeping aspects of this job, however, differentiates it from the other information processing sites. Through applying cognitive task analysis we were able to discern the particular cognitive functions demanded of these employees and recognize thinking skills that benefit performance in the position. The file clerks deal with a vast and complicated body of facts with rigorous schemas for coding and filing. They are intimately familiar with the files to which they are assigned and regularly recognize information such as the names and numbers of clients and cases from memory. The clerks are also familiar with types of law and types of legal documents, in addition to knowing relevant information regarding other company employees.

Factual information is at the core of all the procedures which records center clerks perform. Examples of tasks they are responsible for include filling a request form by phone and receiving one over the printer which in turn would initiate a search. New knowledge is generated by using these facts around requests against their filing knowledge and experience. Problem solving often revolves around successfully completing a request where there is not sufficient information about the document requested. This usually involves (a) making inferences from the available information to narrow down the query (b) doing searches using the computerized and/or physical indexes or using the files themselves, or (c) attempting to obtain more information by communicating with the person requesting the document or that person who is holding it. Therefore problem solving takes the form of querying an elaborate network of facts, both within the clerks own knowledge and within that knowledge imbedded in the firm's database systems.

These findings suggest that indexing knowledge according to the proposed model is based on distinctions (among facts, procedures, mental models and images) that are meaningful. Cognitive task analysis allowed us to gain insight into the rich web of factual information record clerks employ in their procedures. Through this analysis, we were able to recognize differences in the cognitive skills needed across jobs that would on the surface all appear to serve the function of "information processing".

Apart from distinctions pertaining to the nature of the job, our data also reflected differences in the knowledge that front-line, entry level workers possess as a result of the organizational structure in which they perform their work. This analysis provides valuable information with respect to the issues that this study was designed to inform, namely the changes in skill demands that are going on in today's workplace. In moving through our sites of study, we recognized two significant trends in skill demands occurring within our sites which are in direct contrast to one another. One trend is that of transforming traditionally low-skill front-line jobs, such as clerical jobs, into ones which provide front-line workers with increased responsibility and access to information. The contrasting trend is placing de-skilled laborers in front-line positions. We see this occuring in fields where front-line positions have traditionally been filled with highly skilled workers. We found cognitive task analysis to be an adept tool which enabled us to recognize

significant distinctions in the effects of these organizational decisions on worker's knowledge and performance.

Site 3, the customer service department of a large paper company, provides an excellent example of an organization which has attempted to provide entry-level, front-line workers with increased access to information and responsibility. Three years before we examined the firm, it had gone through a structural re-organization which moved traditionally segmented processes such as order entry, customer service, and billing, into "high-performance work teams" that were responsible for "all aspects of the revenue cycle". The teams were made up of typically five to seven employees who shared responsibility for meeting performance goals. Within each team, workers rotated procedures on a bi-monthly basis in order to gain experience in a variety of work related skills. Team members worked closely with one another, continually asking questions and exchanging pertinent information about the organization, about their customers, and about social activities- for example their daily and weekly schedules. This team based environment allowed knowledge to be exchanged very easily, in a manner which accommodated the workers' immediate needs. We found this organization made unique use of the workers' knowledge, and allowed them to continually add to this knowledge set.

As was argued earlier, data about job related knowledge that is not apparent in performance, can prove to be highly informative about the nature of a given position. **Site 4**, the data entry department of a clothing manufacturing company, serves as another example in this argument. Data entry is a job that if it were to be described as a list of observable behaviors would appear to be a series of mechanistic actions. And in fact, in the cognitive aspects of the job as described in our FIPM schema, procedural knowledge is predominant. However, we were also able to elicit factual knowledge about the company that doesn't appear to be necessary to perform this particular job, as well as a systems understanding of the company's organization and the flow of information between different parts of the company (which we classify as being mental model knowledge). In addition, open-ended questions aimed at capturing cognitions about the social context also elicited informal knowledge (procedural) about efficiently communicating with other departments of the company.

Workers in site 3 made an interesting contrast against those in site 4. While the customer service employees were responsible for the same order entry duties as the workers in site 4, the customer service activities were done in the context of the "entire revenue cycle" which the team was responsible for. Through rotating tasks related to all aspects of this cycle, workers attained rich mental models about the organizational systems in place. And by being organized in such a way that this knowledge could be transmitted easily, the entire team benefited from individual worker's knowledge gains. While in both cases we elicited evidence of systemic knowledge, we saw that the customer service workers were asked to use this mental model knowledge continuously in order to manage tasks surrounding the revenue cycle. Their job was described as being "multi-functional", and all of these various functions were concerned with this cycle. The data entry employees in site 4, while having some mental model knowledge surrounding their procedures, were generally not asked to use this knowledge in the course of their work.

The difference between these two organizational structures and the way in which workers knowledge is utilized is marked and appears to account for striking differences in performance. The customer service department at site 4 is able to function virtually without supervision, and is able to experiment and find solutions to problems in a way that the workers in the other site did not approach. By organizing responsibilities in this manner, workers were better able to troubleshoot and make high-level decisions about specific cases. When asked to describe workplace success stories, these employees generally answered with cases relating to a high-order change they brought about in their work processes. This is in contrast to the workers in site 4, whose success stories related to common procedural problems which they were able to overcome.

Additionally, by organizing the worker's responsibilities in terms of the whole revenue cycle, workers were able to use factual information pertaining to their responsibilities in multiple procedures. For example, the customer service employees were responsible for procedures such as handling orders, entering data, coordinating with trucking and mills, collecting payment, and resolving deductions. Within this group of procedures, we saw a tremendous overlap in terms of the factual information needed to perform these procedures. Examples of this factual information include, information about the customer, price of products, warehouse location, and shipping date. This organization of facts and procedures is in contrast

with that of the clothing manufacturer, as well as with most traditional organizational efforts. Tracing the path of facts and procedures within the organization not only lends evidence for the differences between these particular sites, but also points to cognitive task analysis as a tool that can serve to evaluate organizational structures in terms of these differences.

A parallel contrast which also looks at skills demanded of entry-level, front line workers concerns sites 1 and 5. In case study 1, we looked at x-ray technicians working in a hospital setting. **Site 5** involves home health aides who provide health care in the greater Los Angeles area.

The primary responsibilities of the home health aides in case study 5 revolved around driving to patients homes, collecting information about the patients' well-being, and recording this information in a uniform manner. Aides were also responsible for bathing the patient, in addition to several other incidental chores. In cases when aides discovered abnormal occurrences, they would confer (via telephone) with their supervisors about the case, and proceed to follow their supervisors' instructions. The job requires very little in the way of imagistic, factual, or mental model type knowledge. The procedural knowledge needed by these workers generally revolved around their asking questions, bathing patients, recording information, and scheduling visits. The agency which employs these aides also employs LVNs, RNs, and medical doctors. It is these more advanced employees who take on diagnostic health care duties.

Our analysis of case study 1 showed that the x-ray technicians utilized comparatively more varied and involved knowledge in the course of their duties. Here, we saw workers incorporate involved factual, imagistic, procedural and mental model knowledge in areas as diverse as human anatomy, x-ray equipment functionality, and radiology. This knowledge allowed workers to obtain x-rays even in cases where the health status of the patient was unusual, or the circumstances behind the x-ray were out of the ordinary. In addition, the x-ray technicians' knowledge went clearly beyond proper use of the equipment and patient positioning, into medical knowledge about which types of medical procedures require particular types of x-rays. This knowledge allowed technicians to continually reassess their methods according to their given situation.

The x-ray technician's job is presently a high skill entry level job that requires state licensing and certification. While we were on site, the technicians repeatedly voiced concern about a trend in health care reform which would eliminate this licensing requirement. Workers believed that the training which accompanied licensing was a mandatory prerequisite for safe and intelligent operation of x-ray equipment, and was critical to their patients' health and well-being. This same trend appeared to have already occurred in the home health field, where RNs and LVNs were increasingly being replaced by aides. Although in most cases, surface level observations of tasks which these positions are responsible for appear to be straightforward, there are many procedures, as was described earlier, which are significantly informed by deep underlying knowledge. As the trend to de-skill these entry level, front-line workers continues, there is a threat that the de-skilled workers will not have sufficient knowledge to inform decisions in an adequate portion of the cases they are exposed to.

We see, then, that a traditional job description of the home health aide and the x-ray technician positions would yield considerable similarities. On the surface, both work to provide health information for doctors who would then go on to analyze that information. The cognitive task analysis approach yields stark differences between the knowledge needed in order to perform the two positions, as well as in the worker's ability to adapt and work through critical incidents.

Indexing knowledge in terms of facts, images, procedures and mental models has thus yielded distinctions between jobs that capitalize on a major insight of cognitive science, namely that forms of knowledge can be made distinct and may account for performance. In addition, our emphasis on ethnographic and unstructured interviewing methods provide us with rich interpretive data. Together these provide a means by which cognitive task analysis may be performed that incorporates the rich contextual information inherent in the workplace.

Summary of Conclusions, and Implications for Research and Development

The FIPM model of cognitive task analysis has enabled us to make unique distinctions between jobs in terms of the knowledge required to perform those jobs. We feel as though one area which may significantly benefit from these sorts of findings is that of job descriptions. Were jobs to be described not in terms of overt acts, but in terms of cognitive activities, we may be able to enact a system which better matches cognitive skills, to tasks which incorporate those skills. Also, by placing these descriptions in situated accounts, job seekers may begin to have access to materials which more accurately reflect the positions they consider.

Cognitive task analysis has also exhibited great potential for informing areas that surround organizational structure. In each of these cases described, and in all of the sites we visited, we found that workers had knowledge about their organization which went far beyond that which was required of them to perform their job. This knowledge often came about through informal processes in which information about the organization was exchanged. As stated in the section contrasting the customer service group (site 3) with the order entry department (site 4), workers can put this knowledge to effective use in cases where the organizational structure permits such activity. Cognitive task analysis, then, may serve as a tool to inform organizational decisions around how to best structure workers so that the organization makes most effective use of their workers' knowledge. An effective structure would optimize performance, as well as allow knowledge to be transmitted between workers in a productive manner. In our study, we have found that those organizations which allow workers to put their knowledge to full use and those which are structured in such a way that informal knowledge is communicated between workers on a regular basis, demonstrate differences in both attitude and performance.

In terms of methodology, we found that the task matrix approach to querying subjects was successful in its allowing us to verify our field notes, reduce jobs into a group of meaningful tasks, and in its ability to describe each of these tasks in terms of the knowledge types required for performance. While the data which came out of the task matrix was largely qualitative (due to the fact that each subject had varying ideas about what constituted an image, fact, etc.) we see an opportunity to further hone this methodology into one which could be analyzed quantitatively. As we are better able to develop cues which are more definitively interpretable, we will be able to more powerfully recognize correlations in the way people think about their work. A major goal as far as future efforts are concerned, then, is to hone our methods so that they may better correlate with the type of data they are expected to elicit.

Another important aspect of this research concerns the ability for the workplace knowledge to be represented and used to inform instruction and training efforts. To the degree that our research was done within the workplace and attempted to characterize events in the actual context of their taking place, the data we draw upon in analysis is specifically situated in workplace culture and attitudes. Additionally, this data is well-structured around both the given tasks and the types of knowledge which are required for performing those tasks. Cognitive task analysis, thus, is a potentially viable source for site-specific, situation-based educational materials (Ferguson). We see that materials of this nature are used in instructional technology corporate training efforts, as well as in elementary schools (Black & Liepolt)

Through examining and formalizing the knowledge workers need in order to perform their jobs, we also were able to gain a unique look at the types of materials used in supporting these cognitive activities. We feel as though there is considerable possibility for analytic tools such as these to be used in examining the phenomenon of shared cognition. Workers in site 6, the law firm copy center, for example, relied considerably on the ability of their machines to provide feedback and guidance. We witnessed cases in which employees were able to use knowledge about this interface to "trick" the machine into performing tasks other than what the interface would otherwise lead an observer to believe. As these relationships between technology and workers grow more prevalent and complex, new tools will need to be developed which analyze these relationships, and aid workers in performance.

In summary, we have established that our model of knowledge representation is effective in capturing rich knowledge content both in relation to the performance of specific tasks and in relation to the general work setting. Future efforts in this area may have significant effects on areas such as job classification, industrial organization, instruction and technological implementation.

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